



Assessing bone and muscle health and their association in a Mongolian population aged 40 and older: a pioneering observational study

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Abstract

Summary This study in Mongolia reveals that weaker grip strength and higher sarcopenia risk are linked to greater fracture risk and lower bone density. It highlights the crucial interplay between muscle and bone health, emphasizing the need for integrated musculoskeletal assessments to prevent fractures, especially in aging populations.

Background Research on the relationship between bone and muscle health in low- and middle-income countries, particularly Central Asia, remains limited.

Objectives To explore the correlation between muscle and bone health and to estimate the FRAX risk for major osteoporotic fractures (MOF) and hip fractures in the Mongolian population, stratified by age and sex.

Methods A cross-sectional study was conducted in Ulaanbaatar and regional Mongolia from May to August 2024. Handgrip strength, sarcopenia risk (SARC-F) and bone mineral density using peripheral DXA (BMD T-score) were assessed. Fracture risks were estimated using the FRAX model.

Results Participants ($n = 857$; median age, 52 years; 53.0% women) had a median grip strength of 28 kg and a median BMD T-score of -1.9 . Most (69.5%) were at low sarcopenia risk ($SARC-F < 4$). SARC-F was moderately correlated with FRAX scores for MOF and hip fractures ($r \approx 0.27$, $p < 0.001$) while grip strength was negatively correlated with FRAX scores ($r = -0.24$, $p < 0.001$). Grip strength positively correlated with BMD T-scores ($r = 0.22$, $p < 0.001$). Fracture risks increased with age, with women showing higher rates than men. Higher sarcopenia risk ($SARC-F \geq 4$) was associated with lower BMD and increased fracture risk. Lower grip strength (< 18 kg for women, < 28 kg for men) was linked to higher fracture risk and lower BMD.

Conclusions This study highlights the interconnected nature of muscle and bone health in the Mongolian population, demonstrating that lower grip strength and higher sarcopenia risk are significantly associated with increased fracture risk and reduced bone density. These findings underscore the importance of integrated strategies for musculoskeletal health assessment and fracture prevention, particularly in aging populations.

Keywords Muscle strength · Sarcopenia · Bone mineral density · FRAX · Osteoporotic fractures · Mongolian population

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Introduction

Bone and muscle health are key determinants of overall health and important predictors of a wide range of clinical outcomes, particularly in ageing populations [1]. As integral components of the musculoskeletal system, bone and muscle not only contribute to physical strength, mobility and independence, but also serve as indicators of broader health problems. Deterioration of bone health, manifested by conditions such as osteoporosis, and muscle health, manifested

by sarcopenia, are associated with increased morbidity and mortality, with significant public health implications [2]. Both conditions are common in older adults, and their prevalence is expected to increase in line with global ageing trends [3]. Understanding these conditions is paramount to predicting and preventing adverse health outcomes such as fractures, disability and loss of autonomy [4, 5].

Importantly, bone and muscle health are interrelated, with recent research suggesting that they share common aetiological pathways [6]. The concept of the 'bone-muscle unit' emphasises the bidirectional interactions between these two tissues. Mechanical loading from muscle contractions plays a critical role in maintaining bone strength, while bone provides a structural basis for muscle attachment and function. This dynamic relationship implies that impairments in one system may adversely affect the other, with the potential for a cascading effect on health outcomes [7]. Understanding the relationship between bone and muscle health is therefore essential for improving the prevention, diagnosis and treatment of musculoskeletal disorders.

Despite a growing body of research examining the link between bone and muscle health, there remains a notable gap in data from low- and middle-income countries, particularly in Central Asia [8]. The Mongolian population has undergone significant demographic transitions, with a rising proportion of older adults [9]. According to national health reports, life expectancy has steadily increased over the past two decades, leading to a greater potential prevalence of age-related conditions such as osteoporosis and sarcopenia. Mongolia, with its unique demographic, environmental and nutritional profile, represents an important but understudied context for musculoskeletal health research. Several contextual factors may influence the musculoskeletal health of the Mongolian population, although the scientific evidence is rather scary. The harsh continental climate, characterized by long winters and limited sunlight, contributes to reduced cutaneous vitamin D synthesis, a factor linked to lower bone mineral density and increased risk of osteomalacia and sarcopenia [10, 11]. Traditional Mongolian diets, while rich in meat and dairy, may lack sufficient intake of fresh fruits, vegetables and calcium-rich fortified foods, contributing to sub-optimal calcium and micronutrient intake [12]. In addition, access to healthcare, particularly in rural and remote areas, remains limited due to infrastructure constraints, reducing opportunities for early diagnosis and preventive care for musculoskeletal conditions [13]. These environmental and lifestyle factors may collectively contribute to compromised bone and muscle health in the Mongolian adult population. The only few studies focusing on regions such as Inner Mongolia have also provided some insights. For instance, Zhang et al. conducted a comparative study between Japanese and Inner Mongolian young premenopausal women,

showing that Inner Mongolian women had significantly higher bone mass, attributed to higher calcium intake from dairy, greater body weight, and more physically active rural lifestyles compared to their Japanese counterparts [14]. This suggests that traditional lifestyle and nutritional factors may play a protective role in bone health, at least in younger populations. Similarly, Lin et al. investigated the association between bone mineral density and skeletal muscle with fracture risks in postmenopausal women in Inner Mongolia and found that lower skeletal muscle mass was significantly associated with lower BMD and increased fracture risk, reinforcing the interdependence of muscle and bone health in aging women [15]. However, these studies are limited to specific subpopulations and do not encompass the broader adult demographic. Moreover, research directly involving Mongolian populations is limited. Fujihara et al. compared the correlation between atherosclerosis and osteoporosis in women from Japan and Mongolia, providing valuable data but focusing primarily on cardiovascular and bone health correlations [16]. Lkhagvasuren et al. examined the relationship between reproductive hormonal levels and osteoporosis among Mongolian women, offering insights into hormonal influences on bone density [17]. Despite these contributions, there remains a notable gap in comprehensive studies assessing both bone and muscle health and their interrelationship in the general Mongolian adult population [18]. The present study aims to fill this gap by conducting the first observational study to assess bone health, muscle health and their relationship in a sample of Mongolian adults.

Methods

Study design and participants

A cross-sectional study was conducted in various Health Units across Ulaanbaatar and in the Central, Eastern, Western and Khangai regions of Mongolia. Participants were recruited, between May 2024 and August 2024, from Health Unit in two urban districts in Ulaanbaatar (Chingeltei and Songinokhairkhan) and five rural provinces located in Govi-Altai, Khentii, Dornogovi, Tuv and Khuvsgul. The study population was selected based on the following criteria: Men and women aged 40 and above who provide informed consent, reside in the selected district, do not take calcium and vitamin D supplements and are able to walk independently. This study received ethical approval from the ethics committee of the Mongolian National University of Medical Sciences (MNUMS, No.: 2024/3–05). All participants provided informed consent by signing a consent form prior to participation.

Measurements

Muscle health

Handgrip strength was measured with participants in a standing position, arms relaxed and straight down at their sides. The maximum grip strength of each hand was recorded three times alternately using a digital hand dynamometer (T.K.K. 5401, Takei Scientific Instruments Co., Ltd., Tokyo, Japan). Each measurement was followed by a 60-s rest interval to prevent muscle fatigue. After completing three measurements for each hand, the highest recorded grip strength value was selected for analysis [19, 20]. These measurements were then used to stratify participants based on grip strength cut-offs defined by the Asian Working Group for Sarcopenia (< 18 for women and < 28 for men). The T.K.K. A total of 5401 was selected due to its widespread use in clinical practice in Mongolia and its established reliability for muscle strength assessment [21]. The device was calibrated according to the manufacturer's guidelines to ensure measurement accuracy.

The 6-m walk test was performed to assess lower body function and gait speed, with the time taken to complete the distance recorded.

Self-reported physical activity levels were obtained using a standardized questionnaire, using guidelines of the World Health Organization (WHO) [22].

The Sarcopenia Risk-Factor (SARC-F) test was used to assess the risk of sarcopenia. The total SARC-F score is 10. A higher score indicates an increased risk of sarcopenia (score between 0 and 3: low risk of sarcopenia; score between 4 and 7: moderate risk of sarcopenia; score \geq 8: high risk of sarcopenia).

Bone health

Fracture risk calculation using the FRAX model The study used a validated FRAX scores specific to Mongolia to calculate the 10-year probability of a major fracture (hip, spine, humerus or wrist fracture) and hip fracture [23]. FRAX scores are based on risk factors of fracture, including age, gender, body mass index, previous fracture, family history of hip fracture, use of glucocorticoid, rheumatoid arthritis, secondary osteoporosis, current smoking status and alcohol use and BMD of the femoral neck bone. The trained public health nurses calculated the FRAX model of participants by the FRAX Web Version 1.4.6 [24].

Bone mineral density (BMD) was assessed using the EXA- PRESTO-OsteoSys 2022), peripheral Double X-ray Absorptiometry (DXA) for measuring the forearm. The use of this tool was chosen over classical DXA due to its cost-effectiveness and feasibility in clinical practice in Mongolia, where classical DXA machines are not widely available, particularly in regional health centers. The BMD was measured

in the participant's dominant hand (typically the right hand). If the participant had a previous injury or damage to the right hand, the left hand was used for the measurement. In cases where the left hand was injured, the right hand was assessed instead. To ensure accuracy in this study, all measurements were performed by trained personnel. The T-score, a standard measure derived from the BMD, was used to interpret the results according to the World Health Organization (WHO) criteria for diagnosing osteoporosis. The T-score compares an individual's BMD to the average peak BMD of a healthy young adult of the same sex, typically around the age of 30. The score is expressed as the number of standard deviations (SD) above or below this average peak bone mass. A T-score of -1.0 or higher indicates normal bone density (within 1 SD of the young adult mean); a T-score between -1.0 and -2.5 suggests osteopenia, a T-score of -2.5 or lower is indicative of osteoporosis, meaning significantly lower bone density compared to a young adult [25].

Socio-demographic data

Trained nurses conducted the measurements, and participants were asked to complete a questionnaire to assess various socio-demographic factors, including age, sex, body mass index (BMI), waist circumference, level of education, physical activity (defined as at least 30 min of exercise on at least 5 days per week), sedentary behavior (defined as sitting for at least 6 h per day) and menopausal status.

Statistical analysis

The normality of the variables was tested using the Shapiro–Wilk and Anderson–Darling tests. Continuous variables with a normal distribution were expressed as mean and standard deviation, while variables not following a normal distribution were presented as median and interquartile range. Categorical variables were reported as frequencies and percentages. Spearman correlations, adjusted for age, sex and BMI, were conducted between muscle and bone data. The strength of the Spearman correlations was classified as very weak (0 to 0.19), weak (0.20 to 0.39), moderate (0.40 to 0.59), strong (0.60 to 0.79) or very strong (0.80 to 1.00). Mean values of the FRAX scores for major fracture risk and hip fracture risk were presented according to participants' age groups and sex.

The associations between grip strength and fracture risks or BMD were evaluated using specific cutoff values of grip strength (18 for women and 28 for men). The association between sarcopenia risk, as assessed by SARC-F (\geq 4), on fracture risk and BMD was also analyzed. Group comparisons were conducted using the Mann–Whitney U. The data

were analyzed using SPSS Statistics Version 28 software, with a significance level set at 0.05.

Results

Socio-demographic data

Table 1 presents the socio-demographic characteristics of the study population ($N = 857$, age range 40–84), stratified by sex. Women represented 53.0% of the sample. The median age was slightly higher in women (53.9 years; IQR, 46–61) compared to men (51.6 years; IQR, 42–59) ($p < 0.01$). Smoking was significantly more prevalent in men (42%) than in women (8%) ($p < 0.01$). Regarding education level, men were more likely to have completed high school (62.5% vs. 48.6%), whereas women had a higher prevalence of university degrees (32.5% vs. 24.6%) ($p < 0.001$). As expected, handgrip strength was significantly lower in women than in men (median, 21.5 kg vs. 32.9 kg; $p < 0.001$),

with 24.2% of women and 21.6% of men falling below the sex-specific cut-off values. The SARC-F score indicated a higher risk of sarcopenia in men, with 47.4% classified as moderate risk compared to 30.9% of women ($p < 0.001$). The FRAX score for major osteoporotic fractures and hip fractures was significantly higher in women than in men ($p < 0.001$). Similarly, bone mineral density (T-score) was lower in women than in men ($p < 0.001$).

Mean FRAX scores by age group and sex

The risk of major fracture is higher in women than in men starting from age 45 (Table 2).

Based on linear regression, age and sex are significant factors explaining the variation in the FRAX MOF score. Each additional year of age increases the score by 0.1627 units, and women have an average score 1.03 units higher than men, with both variables showing highly significant differences.

Table 1 Socio-demographic data of the population ($N = 857$)

	Women ($n = 454$)			Men ($n = 403$)			<i>p</i> -value
	<i>N</i>	Median (P25–P75)	<i>n</i> (%)	<i>N</i>	Median (P25–P75)	<i>n</i> (%)	
Age (years)	454	53.9 (46–61)		403	51.6 (42–59)		< 0.01
Height (cm)	454	158 (154–163)		403	168 (162–173)		< 0.01
Body mass (kg)	454	67.5 (60–77.8)		403	75 (65–85)		< 0.01
BMI (kg/m ²)	454	27.3 (23.6–30.5)		403	26.8 (23.5–29.5)		0.20
Waist circumference (cm)	454	90 (80–99.8)		402	90.6 (80–100)		0.73
Smoker (yes)	454		36 (8)	402		169 (42)	< 0.01
Level of education	452			403			< 0.001
Elementary school			6 (1.3)			9 (2)	
High school			220 (48.6)			252 (62.5)	
College			70 (15.5)			40 (9.9)	
University			147 (32.5)			99 (24.6)	
Other			9 (2)			3 (1)	
Sedentarity: ≥ 6 h a day (yes)	450		172 (38.2)	399		179 (44.9)	0.15
Regular exercise: at least 30 min, 5 days a week (yes)	453		216 (47.7)	401		191 (47.6)	0.57
Menopause (yes)	443		287 (64.8)	NA		NA	NA
Grip strength (kg)	454	21.5 (16–27)		403	32.9 (27–40)		< 0.001
Women < 18 kg (<i>n</i> (%))			110 (24.2%)				
Men < 28 kg (<i>n</i> (%))			87 (21.6%)				
SARC F (/10)	453	2.31 (0–3)		403	2.15 (0–2.5)		< 0.001
Low risk of sarcopenia (0–3)			294 (64.9)			205 (50.9)	
Moderate risk of sarcopenia (4–7)			140 (30.9)			191 (47.4)	
High risk of sarcopenia (8–10)			19 (4.2)			7 (1.7)	
FRAX major osteoporotic fracture (MOF)	453	3.75 (1.93–6.27)		400	2.49 (1.32–3.99)		< 0.001
FRAX HIP	453	1.1 (0.14–1.26)		400	1.37 (0.08–0.78)		< 0.001
BMD (T-score)	454	- 1.92 (- 3.1 to - 0.9)		403	- 1.81 (- 2.9 to - 0.8)		< 0.001

Legend: NA not applicable

Table 2 Mean FRAX MOF scores by age group and sex ($n = 857$)

	Age group (years)	Sex		<i>p</i> -value
		Men	Women	
	40–44	<i>N</i> = 141 2.11 ± 0.23	<i>N</i> = 97 2.09 ± 0.28	0.10
	45–49	<i>N</i> = 57 2.40 ± 0.37	<i>N</i> = 63 3.29 ± 0.35	< 0.001
	50–54	<i>N</i> = 60 2.94 ± 0.36	<i>N</i> = 92 3.96 ± 0.29	0.07
	55–60	<i>N</i> = 47 3.94 ± 0.40	<i>N</i> = 73 4.59 ± 0.32	0.20
	60–64	<i>N</i> = 35 3.81 ± 0.47	<i>N</i> = 61 6.24 ± 0.35	0.002
	≥ 65	<i>N</i> = 60 5.38 ± 0.36	<i>N</i> = 67 8.51 ± 0.34	< 0.001

Data expressed as mean ± SD

Table 3 Mean FRAX hip scores by age group and sex ($n = 857$)

	Age group (years)	Sex		<i>p</i> -value
		Men	Women	
	40–44	<i>N</i> = 141 0.19 ± 0.28	<i>N</i> = 97 0.19 ± 0.31	1
	45–49	<i>N</i> = 57 0.31 ± 0.41	<i>N</i> = 63 0.47 ± 0.83	< 0.001
	50–54	<i>N</i> = 60 0.44 ± 0.48	<i>N</i> = 92 0.56 ± 0.69	< 0.001
	55–60	<i>N</i> = 47 0.80 ± 0.82	<i>N</i> = 73 0.64 ± 0.77	0.007
	60–64	<i>N</i> = 35 1.01 ± 0.79	<i>N</i> = 61 1.54 ± 1.45	0.004
	≥ 65	<i>N</i> = 60 2.77 ± 2.47	<i>N</i> = 67 1.11 ± 1.91	< 0.001

The risk of hip fracture is significantly higher in women than in men up to age 65, after which the trend appears to reverse (Table 3).

Based on a linear regression, age is the only significant factor explaining the variation in FRAX hip, not sex. The

positive relationship shows that for each additional year of age, the FRAX hip score increases by 0.09649 units, with a highly significant *p*-value (< 0.001).

Association between bone and muscle health

A strong positive correlation was observed between FRAX MOF and FRAX HIP ($r = 0.78$, $p < 0.001$), indicating that higher risks for major osteoporotic fractures often coincide with higher hip fracture risks.

Regarding muscle health, SARC-F scores exhibited moderate positive correlations with FRAX MOF and FRAX HIP ($r \approx 0.27$, $p < 0.001$), indicating that poorer muscle function is associated with higher fracture risk. Conversely, grip strength demonstrated a weak negative correlation with FRAX MOF ($r = -0.24$, $p < 0.001$), implying that individuals with reduced grip strength tend to have higher fracture risk. BMD T-scores showed a significant positive correlation with grip strength ($r = 0.22$, $p < 0.001$) and no significant relationship with SARC-F scores.

The complete set of correlation data is presented in Table 4.

Spearman correlations, adjusted on age, sex and BMI, were used.

Participants with a moderate or high risk of sarcopenia (SARC-F ≥ 4) had a significantly higher risk of major osteoporotic fractures ($p < 0.001$), as estimated by the FRAX score compared to the patients without risk of sarcopenia (SARC-F < 4). Participants with a moderate or high risk of sarcopenia have an increased risk of hip fracture. Finally, participants with a moderate or high risk of sarcopenia have a significantly lower T-score, suggesting lower bone density in this group ($p < 0.001$) (Table 5).

For women, lower grip strength (< 18) was associated with higher risks of major osteoporotic fractures ($p < 0.001$), hip fractures ($p = 0.003$) and lower bone mineral density ($p = 0.001$). For men, while there was no significant difference in risk of major osteoporotic fractures, lower grip strength (< 28) correlated with higher risk of hip fractures ($p < 0.001$) and lower BMD T-scores ($p = 0.04$) (Table 6).

Table 4 Association between bone and muscle health ($n = 857$)

	FRAX MOF	FRAX HIP	BMD T-score	SARC F	Grip strength
FRAX MOF	-	0.78 $p < 0.001$	- 0.009 $p = 0.79$	0.27 $p < 0.001$	- 0.24 $p < 0.001$
FRAX HIP	0.78 $p < 0.001$	-	0.06 $p = 0.07$	0.26 $p < 0.001$	0.018 $p = 0.6$
BMD T-score	- 0.009 $p = 0.79$	0.06 $p = 0.07$	-	- 0.06 $p = 0.11$	0.22 $p < 0.001$
SARC F	0.27 $p < 0.001$	0.26 $p < 0.001$	- 0.06 $p = 0.11$	-	- 0.10 $p = 0.04$
Grip strength	- 0.24 $p < 0.001$	0.018 $p = 0.6$	0.22 $p < 0.001$	- 0.10 $p = 0.04$	-

Table 5 Bone data stratified by sarcopenia risk (assessed via SARC-F)

	SARC F < 4 N = 569	SARC F ≥ 4 N = 261	p-value*
FRAX MOF (median, P25–P75)	2.45 (1.44–4.59)	4.25 (2.19–6.60)	< 0.001
FRAX HIP (median, P25–P75)	0.27 (0.10–0.85)	0.66 (0.24–2)	< 0.001
BMD t-score (median, P25–P75)	– 1.8 (– 2.9 to – 0.7)	– 2.4 (– 3.4 to – 1.5)	< 0.001

*Mann–Whitney *U* test**Table 6** Bone data stratified by grip strength cutoff value (Asian Working Group for Sarcopenia)

	Women (n = 454)			Men (n = 403)		
	Grip strength < 18 (n = 110)	Grip strength ≥ 18 (n = 344)	p-value*	Grip strength < 28 (n = 87)	Grip strength ≥ 28 (n = 316)	p-value*
FRAX MOF (median, P25–P75)	4.14 (2.49–7.72)	2.75 (1.79–5.82)	< 0.001	2.76 (1.79–4.95)	2.16 (1.21–3.74)	0.18
FRAX HIP (median, P25–P75)	0.76 (0.24–2.97)	0.34 (0.13–1)	0.003	0.54 (0.14–1.56)	0.22 (0.07–0.70)	< 0.001
BMD t-score (median, P25–P75)	– 2.42 (– 3.32 to – 1.28)	– 1.8 (– 3 to – 0.73)	0.004	– 2.3 (– 3.9 to – 1.3)	– 1.7 (– 2.7 to – 0.7)	0.04

*Mann–Whitney *U* test

Discussion

The relationship between muscle and bone health has been widely studied, but the associations in the Mongolian population are less well understood. In this study, we examined the correlations between muscle and bone data in this specific population. Our results revealed a very weak but statistically significant correlation between the SARC-F and the FRAX MOF ($r = 0.13$), the SARC-F and the FRAX hip fracture risk score ($r = 0.01$), as well as between grip strength and the BMD T-score ($r = 0.08$), indicating an association between these two aspects of health. Individuals at moderate to high risk of sarcopenia (SARC-F ≥ 4) have significantly higher risks of major osteoporotic and hip fractures, along with lower BMD T-scores, indicating poorer bone health. In women, lower grip strength (< 18 kg) is linked to higher risks of fractures and reduced bone mineral density, while men with lower grip strength (< 28 kg) face increased risk of hip fractures and lower BMD. Furthermore, we proposed values for FRAX major osteoporotic fracture and hip fracture risk in the Mongolian population, stratified by age and sex. Our findings showed that the risk of major osteoporotic fractures and hip fractures increases with age in both sexes, with women experiencing higher risk than men.

This study provides the first observational data on bone and muscle health in a Mongolian adult population, providing an essential foundation for future research and public health initiatives. By assessing muscle strength through both

hand grip strength and SARC-F and bone health through both FRAX score and BMD T-score, this research fills a critical gap in the understanding of musculoskeletal health in this region. As well as providing a benchmark for future studies, these findings provide insight into the relationship between muscle and bone health in a population that has been largely under-represented in previous research. Compared to studies in East Asia and other low- and middle-income countries, the BMD T-scores in our cohort (median, – 1.92 in women and – 1.81 in men) are relatively low, suggesting a high prevalence of osteopenia or osteoporosis even in midlife. Similarly, the median grip strength in women (21.5 kg) and men (32.9 kg) is lower than normative values reported in international reference populations (e.g. 25.6 kg in women and 41.1 kg in men aged 50–59 years in European cohorts) [26]. The proportion of participants at moderate to high sarcopenia risk (35.2% overall using SARC-F ≥ 4) is also notable. While direct comparisons are challenging due to methodological and ethnic differences, these findings suggest that musculoskeletal health in Mongolian adults may be comparatively poorer than in other populations. This emphasises the importance of country-specific screening and prevention strategies.

Our observation of comparatively low bone mineral density and reduced muscle strength in the Mongolian adult population is consistent with descriptive findings from other studies in East and Central Asia, which have also reported concerning patterns of musculoskeletal decline, particularly among aging and rural populations [18, 27].

Studies conducted in Inner Mongolia have demonstrated the significant impact of lifestyle and environmental factors on bone health, highlighting the role of traditional dietary habits, climate and physical activity levels [14]. Lin et al. further explored the interaction between muscle mass and bone health in postmenopausal women, supporting our findings of a correlation between grip strength and BMD [15]. Similarly, another study comparing Mongolian and Japanese women showed differences in osteoporosis prevalence due to varying cardiovascular and metabolic factors, suggesting that osteoporosis risk assessment should account for region-specific characteristics [16]. Our study adds to this body of evidence by providing data specific to Mongolia and incorporating both muscle and bone health assessments.

Our findings revealed a significant but weak positive correlation between grip strength and BMD T-score. While this association is consistent with previous studies highlighting the interplay between muscle and bone health, it is important to consider the direction of causality. Given that mechanical loading from muscle contractions is a major determinant of bone strength, it is more plausible that grip strength influences BMD rather than the reverse. Interestingly, some meta-analyses suggested that muscle weakness is a key predictor of fracture risk [28, 29], aligning with our findings that low grip strength is associated with increased fracture probability. Future studies employing longitudinal designs and interventional approaches are needed to establish causality more definitively in the Mongolian population.

However, the results of this study are difficult to compare directly with those of other Asian populations. Differences in population characteristics and assessment tools make it difficult to make broad generalisations. For example, studies conducted in other parts of Asia, such as Japan, China or Korea, have often used different recruitment strategies and more sophisticated imaging techniques, such as dual-energy X-ray absorptiometry (DXA) for bone health [27, 30]. In contrast, we used peripheral DXA rather than classical DXA for BMD assessment. While classical DXA remains the gold standard for osteoporosis diagnosis, its limited availability in Mongolia, particularly in regional areas, necessitated the use of other technique, which is more cost-effective and widely accessible in routine clinical practice. Although peripheral DXA has been shown to be a practical tool for large-scale studies, its accuracy compared to classical DXA may be lower, which should be considered when interpreting the results. Similarly, hand grip strength, although widely used as a proxy for muscle strength, may not be directly comparable with other studies that used more comprehensive assessments of muscle health, not counting the difference between the devices use [31]. Additionally, another limitation of this study is the reliance on self-reported physical activity data, even if we followed the guidelines of the WHO for the construct of our tool. Self-reported measures are prone to

recall bias and social desirability bias, which may lead to overestimation or underestimation of actual physical activity levels. Participants may misinterpret or inaccurately recall their activity levels, leading to potential measurement errors. Future research should consider using objective measures, such as accelerometers or pedometers, to provide a more accurate assessment of physical activity and its association with musculoskeletal health outcomes. These methodological differences should be considered when interpreting the results in a broader Asian context.

Our study's findings align with previous research that has explored the relationship between muscle strength and bone health using ultrasound-based BMD assessments and hand-grip strength measurements. For instance, a study utilizing data from the National Health and Nutrition Examination Survey (NHANES) found that grip strength is associated with increased femoral neck and total lumbar spine BMDs in men, premenopausal women and postmenopausal women [32]. Additionally, research has demonstrated that handgrip strength is associated not only with fracture risk but also with trabecular bone score (TBS) and phalangeal quantitative ultrasound (QUS) measurements [33], which are markers of bone strength. Furthermore, two other studies found some associations of BMI and handgrip strength with BMD measured with quantitative ultrasound of the heel [34, 35]. These studies collectively support the association between muscle strength, as measured by handgrip strength, and bone health indicators obtained through ultrasound-based assessments. Our findings contribute to this body of evidence by providing data specific to the Mongolian adult population, thereby filling a notable gap in the literature.

Despite these challenges, the positive, although weak, and significant relationship observed between bone and muscle health parameters in this study is consistent with findings from previous research [36]. This adds to the growing body of evidence emphasising the interdependence of bone and muscle health. The association between greater muscle strength and better bone health reinforces the concept of the 'bone-muscle unit' and highlights the need for integrated approaches to prevent the deterioration of both tissues [37]. Our findings highlight the importance of developing strategies for early screening and intervention to address these conditions simultaneously. As both osteoporosis and sarcopenia are major contributors to disability and frailty, implementing preventive measures at the community level could have a profound impact on reducing future healthcare burdens.

For Mongolia, a country with limited healthcare infrastructure and no public health insurance or reimbursement system, the implications of these findings are significant. The high prevalence of both muscle and bone health problems identified in this study suggests an urgent need for public health interventions. However, given the financial

constraints and lack of health service coverage, addressing these issues will require cost-effective solutions that can be scaled up to the population level. Community-based screening programmes, public awareness campaigns and affordable lifestyle interventions—such as promoting physical activity, improving diet and possibly incorporating low-cost supplementation—may offer feasible ways to mitigate the impact of musculoskeletal decline in this setting [38, 39].

This study's strengths include its large sample size, which enhances the generalizability of the findings, and the diverse geographic representation from various regions of Mongolia. Additionally, the use of validated measures for both muscle (handgrip strength) and bone health (FRAX model, BMD T-score) ensures reliable data. However, the cross-sectional design limits the ability to draw causal conclusions. The use of a single hand for BMD measurement might also not fully represent bone health, especially in those with injuries. Finally, despite adjusting for age, sex and BMI, other factors such as diet, physical health conditions and medications (e.g. corticosteroids) could influence muscle and bone health but were not controlled for in the analysis.

Looking forward, further studies are essential to build on these initial findings. Longitudinal studies will be essential to understand how bone and muscle health develops over time in this population and how it responds to different interventions. In addition, future research should explore the role of other factors, such as diet, physical activity and environmental exposures, in shaping bone and muscle health in Mongolia. Incorporating more advanced technologies, such as DXA, for more accurate bone density measurements and exploring comprehensive assessments of muscle health beyond hand grip strength could also provide a more nuanced understanding of these relationships.

In conclusion, this study provides novel insights into the relationship between bone and muscle health in the Mongolian population. Our findings suggest that lower grip strength and higher sarcopenia risk are associated with increased fracture risk and lower bone mineral density. However, given the methodological limitations, including the use of peripheral DXA for BMD assessment and reliance on self-reported physical activity data, these results should be interpreted with caution. Clinicians should consider these findings when assessing musculoskeletal health, particularly in resource-limited settings. Future research should incorporate longitudinal designs and objective measurement tools to further validate these findings and inform targeted interventions aimed at improving musculoskeletal health in this understudied population, to ultimately guide effective public health interventions.

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Author contribution Myadagmaa Jaalkhorol, Shiirevnyamba Avirmed, Amarsaikhan Dashtseren and Olivier Bruyere conceptualized, designed and supervised the study, performed the assessment, interpreted the data and edited the manuscript.

Myadagmaa Jaalkhorol, Fanny Buckinx and Olivier Bruyere analyzed the data and drafted the manuscript.

Seded Baatar performed the assessment and reviewed the manuscript. Gerelmaa Ochirdorj performed the assessment and reviewed the manuscript.

Bolormaa Darambazar performed the assessment and reviewed the manuscript.

Batmunkh Batsaikhan interpreted the data and drafted the manuscript.

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Data Availability The data that support the findings of this study are available on request from the corresponding author.

Declarations

Conflicts of interest None.

References

1. Gielen E, Dupont J, Dejaeger M, Laurent MR (2023) Sarcopenia, osteoporosis and frailty. *Metabolism* 145:155638
2. Hirschfeld HP, Kinsella R, Duque G (2017) Osteosarcopenia: where bone, muscle, and fat collide. *Osteoporos Int* 28(10):2781–2790
3. Edwards MH, Dennison EM, Aihie Sayer A, Fielding R, Cooper C (2015) Osteoporosis and sarcopenia in older age. *Bone* 80:126–130
4. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T et al (2019) Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing* 48(1):16–31
5. Cauley JA (2013) Public health impact of osteoporosis. *J Gerontol A Biol Sci Med Sci* 68(10):1243–1251
6. Tagliaferri C, Wittrant Y, Davicco MJ, Walrand S, Coxam V (2015) Muscle and bone, two interconnected tissues. *Ageing Res Rev* 21:55–70
7. Laskou F, Patel HP, Cooper C, Dennison E (2022) A pas de deux of osteoporosis and sarcopenia: osteosarcopenia. *Climacteric* 25(1):88–95
8. Kanis JA, Odén A, McCloskey EV, Johansson H, Wahl DA, Cooper C (2012) A systematic review of hip fracture incidence and probability of fracture worldwide. *Osteoporos Int* 23(9):2239–2256
9. Williams GA, Cylus J, Al Tayara L, Roubal T, Tsilaajav T, Barber SL (2022) Can healthy ageing moderate the effects of population ageing on economic growth and health spending trends in Mongolia? A modelling study. *Health Res Policy Syst* 20(Suppl 1):122

10. Ganmaa D, Tserendolgor U, Frazier L, Nakamoto E, Jargalsaikhan N, Rich-Edwards J (2008) Effects of vitamin D fortified milk on vitamin D status in Mongolian school age children. *Asia Pac J Clin Nutr* 17(1):68–71
11. Uush T (2025) Vitamin D deficiency in Mongolian men aged 15–49 years. *J Steroid Biochem Mol Biol* 247:106656
12. Bromage S, Daria T, Lander RL, Tsolmon S, Houghton LA, Tserennadmid E et al (2020) Diet and nutrition status of Mongolian adults. *Nutrients* 12(5):1514
13. Jigjidsuren A, Byambaa T, Altangerel E, Batbaatar S, Saw YM, Kariya T et al (2019) Free and universal access to primary health-care in Mongolia: the service availability and readiness assessment. *BMC Health Serv Res* 19(1):129
14. Zhang M, Shimmura T, Bi LF, Nagase H, Nishino H, Kajita E et al (2004) Bone mass and lifestyle related factors: a comparative study between Japanese and Inner Mongolian young premenopausal women. *Osteoporos Int* 15(7):547–551
15. Lin Jing AS, Mei D (2022) Association of bone mineral density and skeletal muscle with fracture risks in postmenopausal women in Inner Mongolia area. *Chi J Tissue Eng Res* 26(14):2133–7
16. Fujihara Y, Nawata H, Honda M, Kunitake T, Aida E, Nagai T et al (2017) Comparative study of the correlation between atherosclerosis and osteoporosis in women in Japan and Mongolia. *J Gen Fam Med* 18(5):237–243
17. Lkhagvasuren U, Jav S, Zagdsuren B (2015) Correlation between reproductive hormonal level and osteoporosis among women in Mongolia. *Cent Asian J Glob Health* 4(2):239
18. Cheung EYN, Tan KCB, Cheung CL, Kung AWC (2016) Osteoporosis in East Asia: current issues in assessment and management. *Osteoporos Sarcopenia* 2(3):118–133
19. Chen L-K, Woo J, Assantachai P, Auyeung T-W, Chou M-Y, Iijima K et al (2020) Asian Working Group for Sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. *J Am Med Directors Assoc* 21(3):300–7
20. Roberts HC, Denison HJ, Martin HJ, Patel HP, Syddall H, Cooper C et al (2011) A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. *Age Ageing* 40(4):423–429
21. Jaalkhorol M, Cieřlik A, Dashtseren M, Khairat A, Damdinbazar O, Ochirdorj G, Khurelbaatar T, Batmunkh G, Ganzorig U, Koziel S (2024) The relationship between health parameters, body size, elements of lifestyle, and hand grip strength in a group of patients with type 2 diabetes, aged 40–98, from Ulaanbaatar, Mongolia. *J Clin Med* 14(1):102. <https://doi.org/10.3390/jcm14010102>
22. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G et al (2020) World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med* 54(24):1451–1462
23. Jaalkhorol M, Johansson H, Avirmed S, Dashtseren A, Bruyere O, Lorentzon M et al (2025) A surrogate FRAX model for Mongolia. *Arch Osteoporos* 20(1):27
24. Kanis JA, McCloskey EV, Johansson H, Oden A, Ström O, Borgström F (2010) Development and use of FRAX in osteoporosis. *Osteoporos Int* 21(Suppl 2):S407–S413
25. Kanis JA (2002) Diagnosis of osteoporosis and assessment of fracture risk. *The Lancet* 359(9321):1929–1936
26. Dodds RM, Syddall HE, Cooper R, Benzeval M, Deary IJ, Dennison EM et al (2014) Grip strength across the life course: normative data from twelve British studies. *PLoS One* 9(12):e113637
27. Weng SE, Huang YW, Tseng YC, Peng HR, Lai HY, Akishita M et al (2025) The evolving landscape of sarcopenia in Asia: a systematic review and meta-analysis following the 2019 Asian working group for sarcopenia (AWGS) diagnostic criteria. *Arch Gerontol Geriatr* 128:105596
28. Huang P, Luo K, Xu J, Huang W, Yin W, Xiao M et al (2021) Sarcopenia as a risk factor for future hip fracture: a meta-analysis of prospective cohort studies. *J Nutr Health Aging* 25(2):183–188
29. Yeung SSS, Reijnierse EM, Pham VK, Trappenburg MC, Lim WK, Meskers CGM et al (2019) Sarcopenia and its association with falls and fractures in older adults: a systematic review and meta-analysis. *J Cachexia Sarcopenia Muscle* 10(3):485–500
30. Chandran M, Brind'Amour K, Fujiwara S, Ha YC, Tang H, Hwang JS et al (2023) Prevalence of osteoporosis and incidence of related fractures in developed economies in the Asia Pacific region: a systematic review. *Osteoporos Int* 34(6):1037–53
31. Buckinx F, Landi F, Cesari M, Fielding RA, Visser M, Engelke K et al (2018) Pitfalls in the measurement of muscle mass: a need for a reference standard. *J Cachexia Sarcopenia Muscle* 9(2):269–278
32. Luo Y, Jiang K, He M (2020) Association between grip strength and bone mineral density in general US population of NHANES 2013–2014. *Arch Osteoporos* 15(1):47
33. Catalano A, Gaudio A, Bellone F, La Fauci MM, Xourafa A, Gembillo G et al (2022) Trabecular bone score and phalangeal quantitative ultrasound are associated with muscle strength and fracture risk in hemodialysis patients. *Front Endocrinol (Lausanne)* 13:940040
34. Ali K, El Said SM, Adly NN, Abdul-Rahman SA (2019) The relation between calcaneus stiffness index as a measure of bone density and body mass index in an Egyptian cohort. *J Multidiscip Healthc* 12:1085–1090
35. Nagai A, Tajika T, Yamamoto A, Okura C, Kanazawa S, Takagishi K (2017) Relations between quantitative ultrasound assessment of calcaneus and grip and key pinch power in Japanese mountain village residents. *J Orthop Surg (Hong Kong)* 25(1):2309499017690321
36. Locquet M, Beaudart C, Durieux N, Reginster JY, Bruyere O (2019) Relationship between the changes over time of bone mass and muscle health in children and adults: a systematic review and meta-analysis. *BMC Musculoskelet Disord* 20(1):429
37. Cianferotti L, Brandi ML (2014) Muscle-bone interactions: basic and clinical aspects. *Endocrine* 45(2):165–177
38. Papadopoulou SK, Papadimitriou K, Voulgaridou G, Georgaki E, Tsofidou E, Zantidou O et al (2021) Exercise and nutrition impact on osteoporosis and sarcopenia—the incidence of osteosarcopenia: a narrative review. *Nutrients* 13(12):4499
39. Atlihan R, Kirk B, Duque G (2021) Non-pharmacological interventions in osteosarcopenia: a systematic review. *J Nutr Health Aging* 25(1):25–32

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